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A New Technique for Reducing Radar Response to Signals Entering Antenna Sidelobes

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A new technique for reducing a radar's response to undesired signals entering a radar's sidelobes is described and analyzed theoretically. This technique involves moving the phase center of a phased-array antenna to Doppler-shift sidelobe signals out of the radar receiver's passband.

CONTENTS

A NEW TECHNIQUE FOR REDUCING RADAR RESPONSE TO SIGNALS ENTERING ANTENNA SIDELOBES

INTRODUCTION

The purpose of this report is to describe a new method of suppressing undesired echoes that enter the sidelobes of a radar antenna. This will include the results of a theoretical study.

The concept to be discussed was conceived at the Naval Research Laboratory in 1981, and a patent search was initiated. This search found that the concept had been patented in 1968 [1]. Attempts were made to locate the inventors through Motorola who employed them and to whom the patent was assigned. The inventors could not be located, and Motorola had no records of work done on the concept. Literature searches also failed to locate any related publications. As a consequence the evaluation program was initiated at NRL.

CONCEPT

The concept involves moving the phase center of a phased-array antenna in the plane of the aperture to Doppler-shift signals radiated and received on the antenna sidelobes out of the passband of the radar receiver. The phase center is moved by illuminating only part of an available phased-array aperture and moving the illuminated part cross the aperture while the antenna is transmitting and/or receiving.

The technique can be implemented by switches in the feed lines of the antenna elements. If N elements are available in the desired dimension, the left-hand M elements ($M < N$) can be turned on for a time τ short compared to the reciprocal of the radar bandwidth. The first left-hand element, or element 1, is then turned off, elements 2 through M are left on, and element $M + 1$ is turned on. Elements 2 through $M + 1$ then radiate for another time τ before a change to radiation from elements 3 through $M + 2$, etc.

If the antenna elements are separated by 1/2 wavelength λ of the radar and if the M excited elements are stepped thrugh $N - M$ positions in the time the radar transmits its pulse of length T, the apparent phase center velocity will be

$$V = (N - M)\lambda/2T. \tag{1}$$

This veocity will produce a Doppler shift on any signal radiated along any line in the plane defined by the normal to the aperture and the direction of motion of the phase center except a line normal to the aperture.

The magnitude and sign of the Doppler shift in a direction making an angle θ with the normal to the aperture in the plane defined by the normal to the aperture and the direction of motion of the phase center will be

$$f_d = V/\lambda = [(N - M)\lambda \sin\theta]/2\lambda T. \tag{2}$$

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Since $1/T = B$, which is the radar bandwidth, (2) can be written as

$$f_d = [(N - M)B \sin \theta]/2, \tag{3}$$

and, by the proper choice of $N - M$, f_d can be made to exceed B at any angle θ_d or greater.

The aperture motion can be continued on receive by repeating the sweep from left to right with abrupt returns from right to left. If this is done, f_d given by (3) will be doubled, reducing θ_d or permitting $N - M$ to be reduced.

THEORETICAL STUDY

A computer simulation of an M-out-of-N-element line array was developed to calculate the far-field response of the antenna in phase and amplitude as the M excited elements were stepped across the array. The response of the array as a function of angle θ was then processed with a fast-Fourier-transform (FFT) package, and three-dimensional plots of antenna response and signal spectrum were made as a function of θ.

Figure 1 is an example plot of the one-way response of a system with $N = 40$, $M = 20$, and no weighting on the aperture or the transmit pulse. In this case, the antenna and spectral responses were $\sin x/x$. The angle between the peak and the first null in the antenna response was arcsin 0.1 radian, and the frequency separation between the peak and the first null in the spectral response was the radar bandwidth B or $1/T$. The peak spectral response moves off zero Doppler as θ moves away from 0. The ordinate of the figure ranges from 0 to 80 dB down.

Figure 2 shows the effect of weighting the 20 excited elements with a Hamming weighting without weighting the transmit pulse. In this case the highest sidelobe in the antenna response is down 42 dB one way.

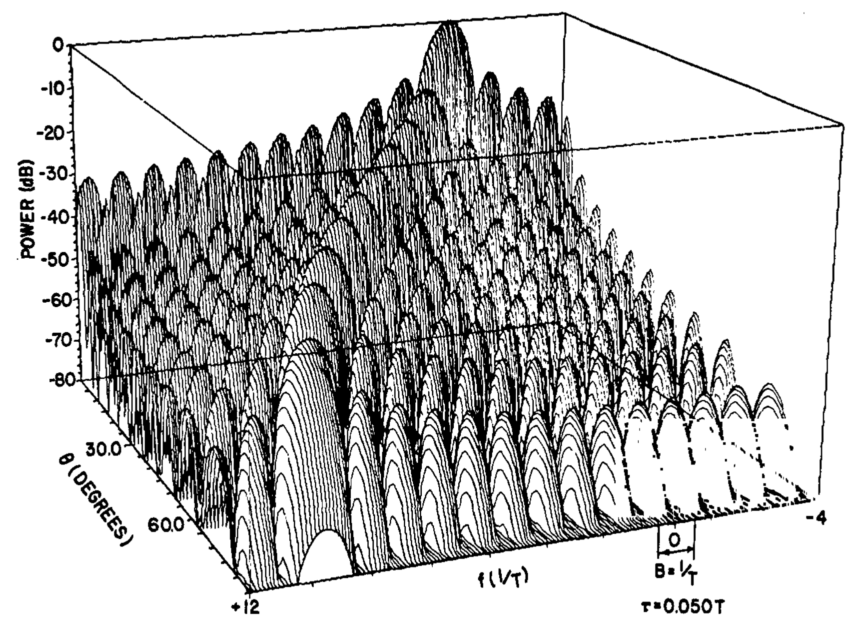

Fig. 1 — One-way response when 20 unweighted elements (forming an unweighted or rectangular aperture distribution) are moved through 20 elements during an unweighted (rectangular) transmit pulse

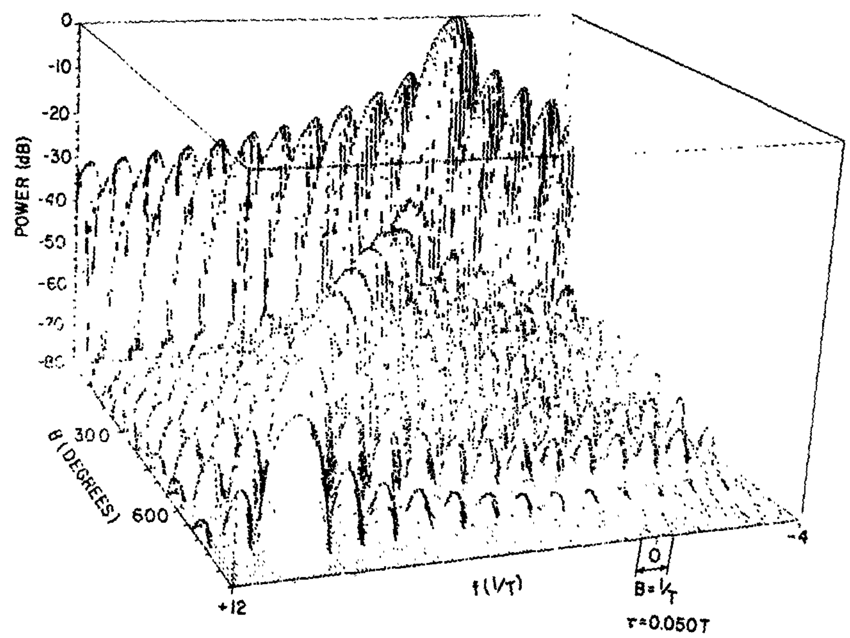

Fig. 2 — One-way reponse when 20 Hamming-weighted elements are moved through 20 elements during an unweighted transmit pulse

Figure 3 is a one-way plot showing the effect of weighting the transmit pulse with a Hamming weighting without weighting the 20 excited elements of the array.

Figure 4 shows how a Hamming weighting of both the transmitted pulse and the 20 excited elements affects the one-way pattern of the aperture.

Figure 5 is the symmetrical one-way response of a ten-element array moved through 20 elements during the transmit pulse of 1-μs duration, with no weighting in space or time. The grating lobes that appear in the spectrum are due to the discrete sampling of the phase center.

Figure 6 is a two-way pattern of the same aperture with the phase center moved both on transmit and on receive. The spectral grating lobes move in nearly to zero Doppler at $\theta = \pm 85°$. However, at this large angle, the antenna sidelobes are the lowest.

This problem of spectral grating lobes can be eliminated by placing the antenna array elements closer together to increase the ratio of the sampling rate to the maximum Doppler shift. Figure 7 is an example of the result of element separations of $\lambda/4$. In this case 20 elements were stepped through 20 elements on transmit to Doppler-shift the response at $\theta = \pm 90°$ by 5 MHz in a 1-μs transmit pulse. The grating lobes at $\theta = 0$ now appear at ± 20 MHz. Thus, on swept receive, the grating lobes would move only to ± 10 MHz and would not be near the receiver passband at zero Doppler.

Another possible solution to the grating-lobe problem would be to use conventional array-element spacings of $\lambda/2$, to sweep M out of N on transmit and $M - k$ out of N on receive, where k is greater than 0 but less than $N - M$. This would keep the grating lobe away from the receiver passband on receive. A third alternative is to sweep the M-element aperture on transmit and to use the full N-element aperture on receive.

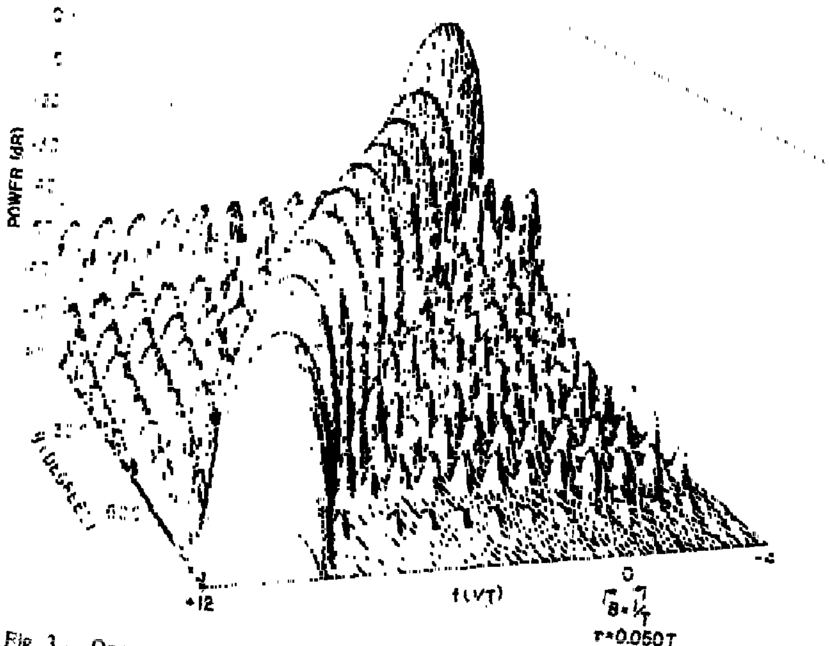

Fig. 3 — One-way response when 20 unweighted elements are moved through 20 elements during a Hamming-weighted transmit pulse

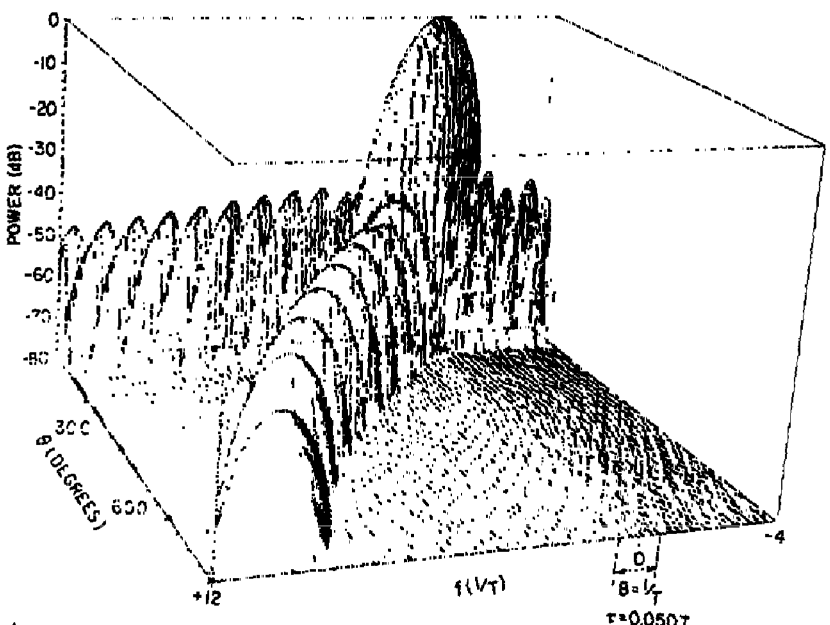

Fig. 4 — One-way response when 20 Hamming-weighted elements are moved through 20 elements during a Hamming-weighted transmit pulse

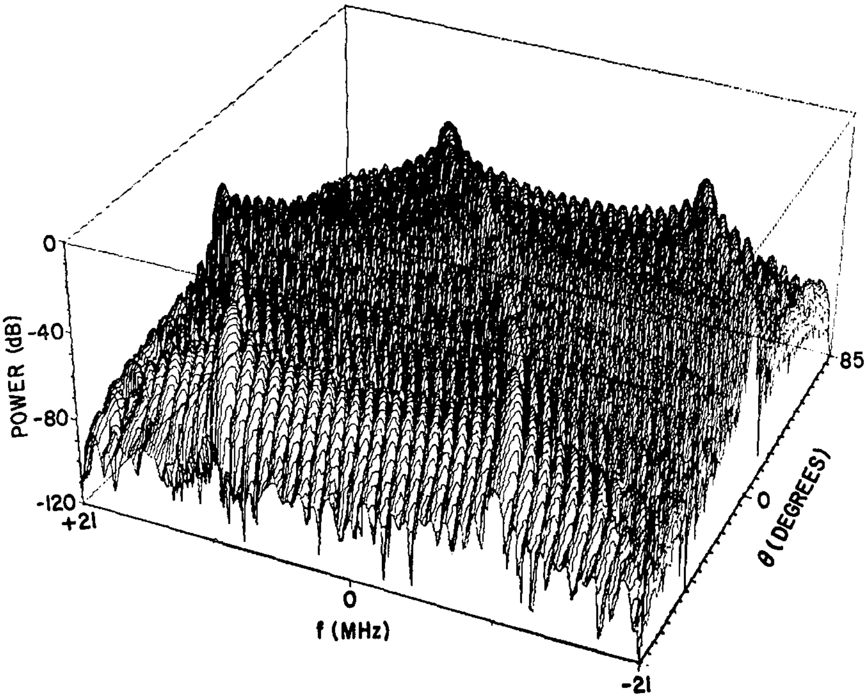

Fig. 5 — One-way response when ten unweighted elements spaced λ/2 apart are moved through 20 elements during a 1-μs unweighted transmit pulse

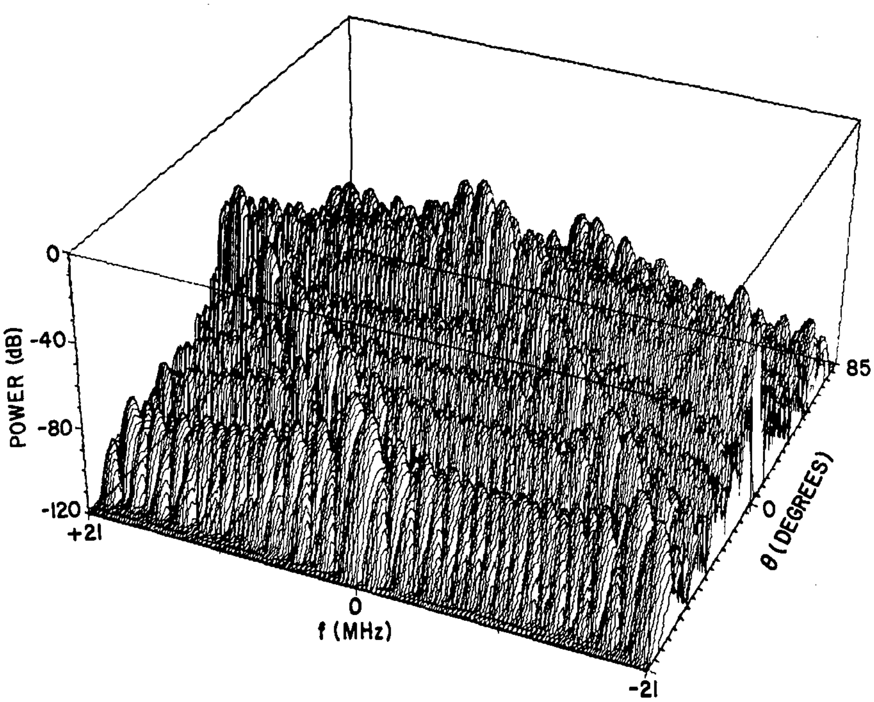

Fig. 6 — Two-way response when ten unweighted elements spaced λ/2 apart are moved through 20 elements during a 1-μs unweighted transmit pulse and an unweighted 1-μs receive pulse

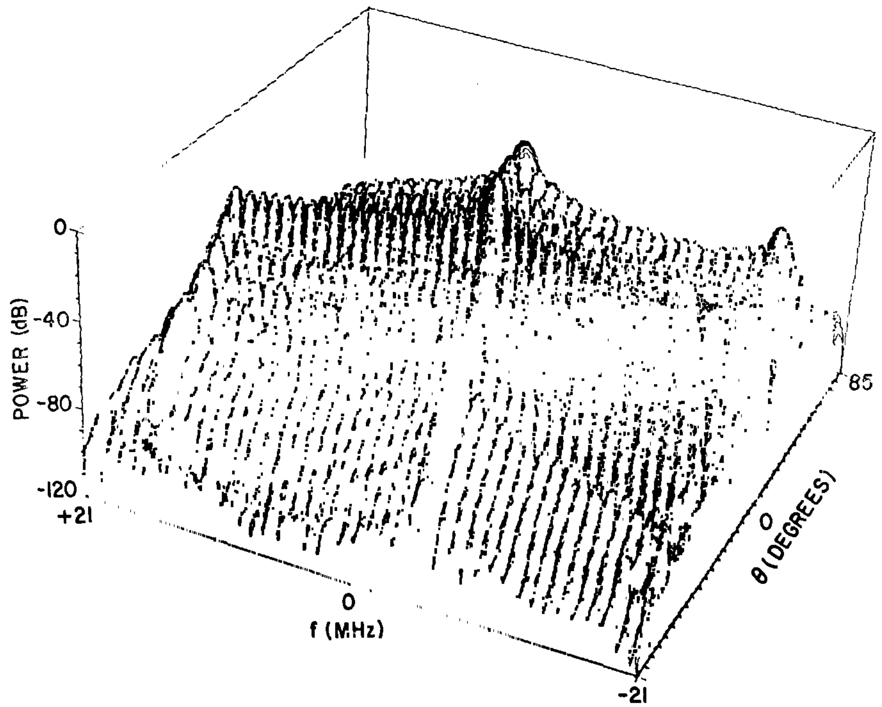

Fig. 7 — One-way response when ten unweighted elements spaced λ/4 apart are moved through 20 elements during 1-μs unweighted transmit pulse

ANTENNA-PATTERN SIMULATIONS

The antenna patterns that would result from a combination of a stepped aperture and a bandlimiting filter on receive were obtained by squaring and adding the FFT coefficients in the assumed radar passband and normalizing to the peak response.

Figure 8a is an example of the use of 20 Hamming-weighted excited array elements stepped through 20 elements separated by λ/2 during the transmit pulse with all 40 available elements with Hamming weighting used on receive. In this case the receive signal was passed through a bandpass filter centered on zero Doppler and with bandwidth B equal to the reciprocal of the transmit pulse length $(1/T)$. Figure 8b is a two-way pattern of an array with 40 stationary Hamming-weighted elements used both on transmit and on receive for comparison with Fig. 8a. Comparison of Figs 8a and 8b shows that a significant reduction is possible with the stepped aperture.

ANTENNA SWEEPS ON RECEIVE

The effect of synchronization errors between the start of the antenna sweep and the echo arrival time on receive was studied. The anticipated antenna patterns that would result from the response of 20 unweighted elements swept through 10 elements separated by λ/2 filtered by the radar receiver were calculated for synchronization errors of 0, $0.1T$, $0.2T$, ..., $0.9T$. Figure 9a illustrates the effect of these synchronization errors. Figure 9b is the pattern of 20 unweighted stationary array elements separated by λ/2 for comparison with Fig. 9a. Comparison of Figs 9a and 9b shows a significant sidelobe reduction via aperture sweeps and filtering, even with the worst synchronization errors.

Figure 10a is the calculated two-way response of a Hamming-weighted 30-element array swept through 15 elements spaced λ/2 apart both on transmit and, with worst-case synchronization error, on receive. Figure 10b is the two-way response of an array of 45 stationary elements with Hamming weighting for comparison with Fig. 10a. Comparison of Figs. 10a and 10b shows that a significant

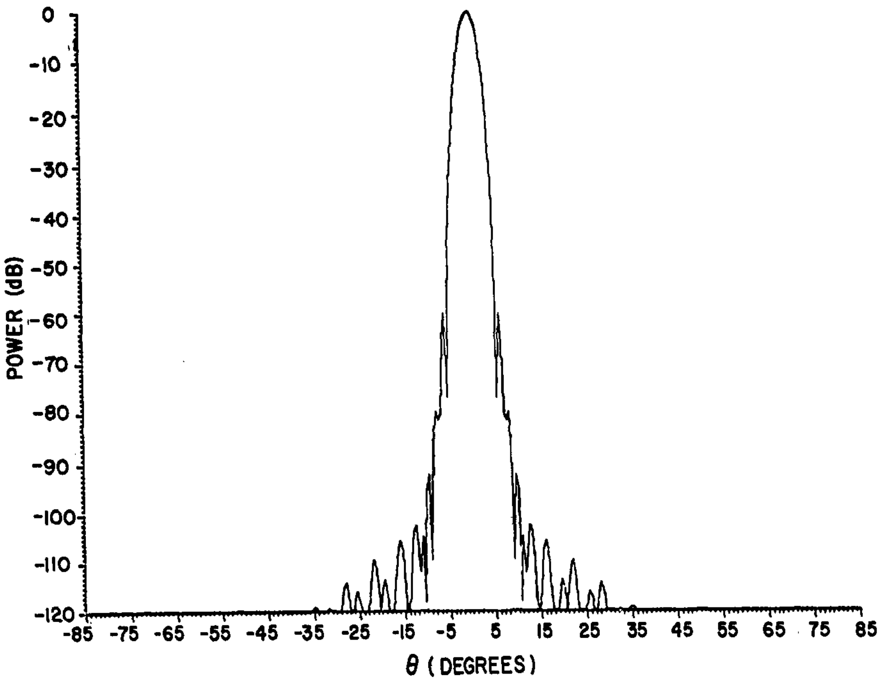

Fig. 8a — Two-way antenna pattern when 20 Hamming-weighted elements spaced λ/2 apart are moved through 20 elements on transmit and 40 stationary Hamming-weighted elements are used on receive

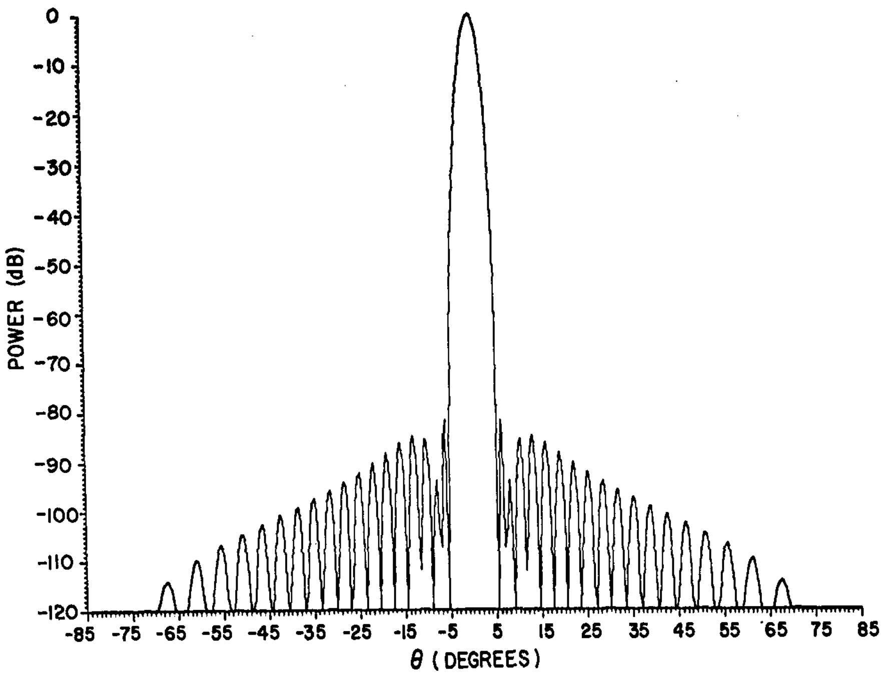

Fig. 8b — Two-way antenna pattern when 40 stationary Hamming-weighted elements are used both on transmit and on receive

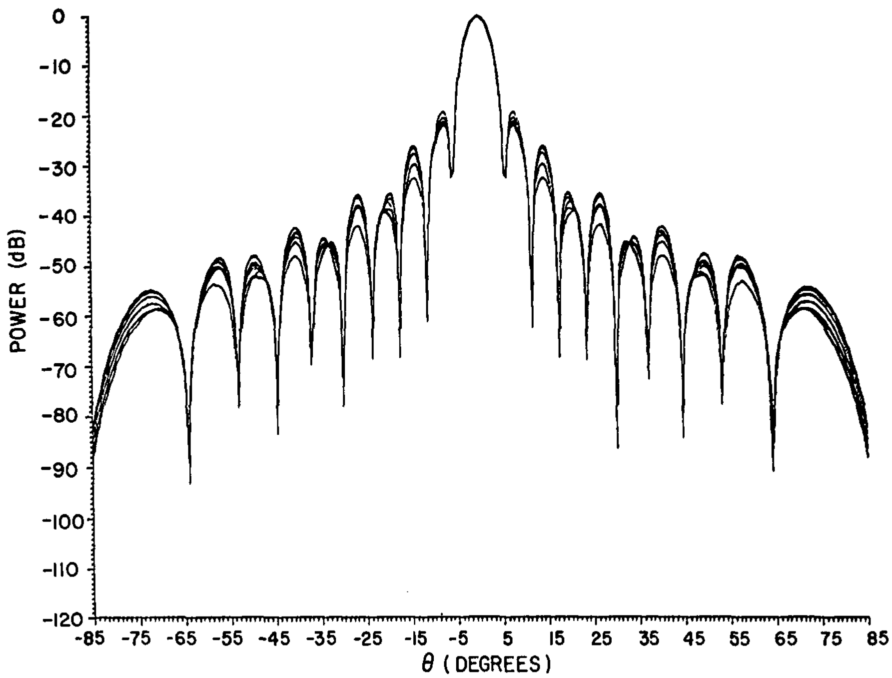

Fig. 9a — One-way antenna pattern when 20 unweighted elements spaced $\lambda/2$ apart are moved through ten elements repeatedly in times equal to the receive pulse length T. There are ten response curves, for time differences (synchronization errors) of 0, $0.1T$, $0.2T$, . . . , $0.9T$ between the sweep start time and the arrival time.

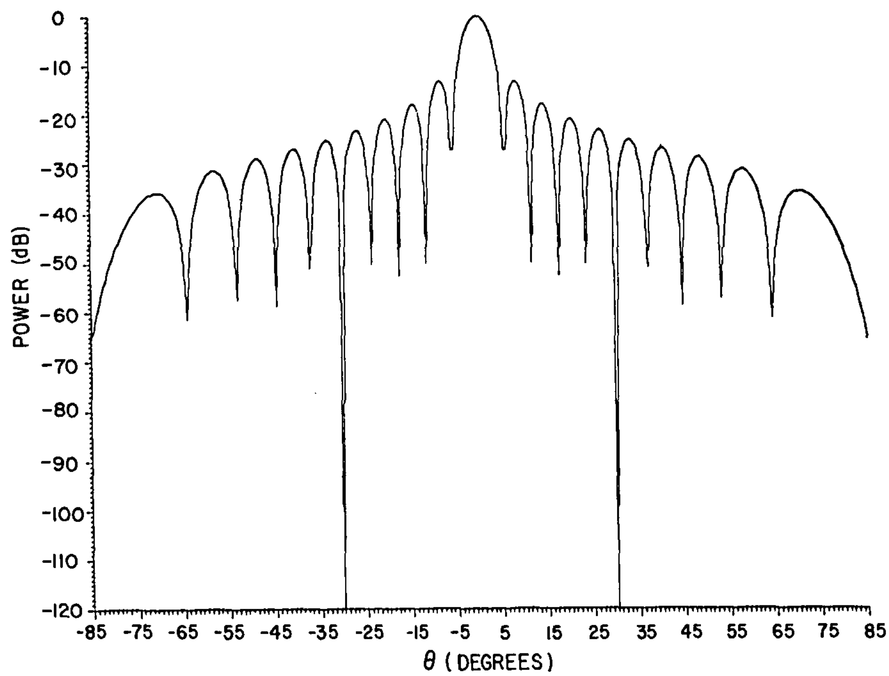

Fig. 9b — One-way antenna pattern when 20 stationary unweighted elements spaced $\lambda/2$ apart are used in transmit

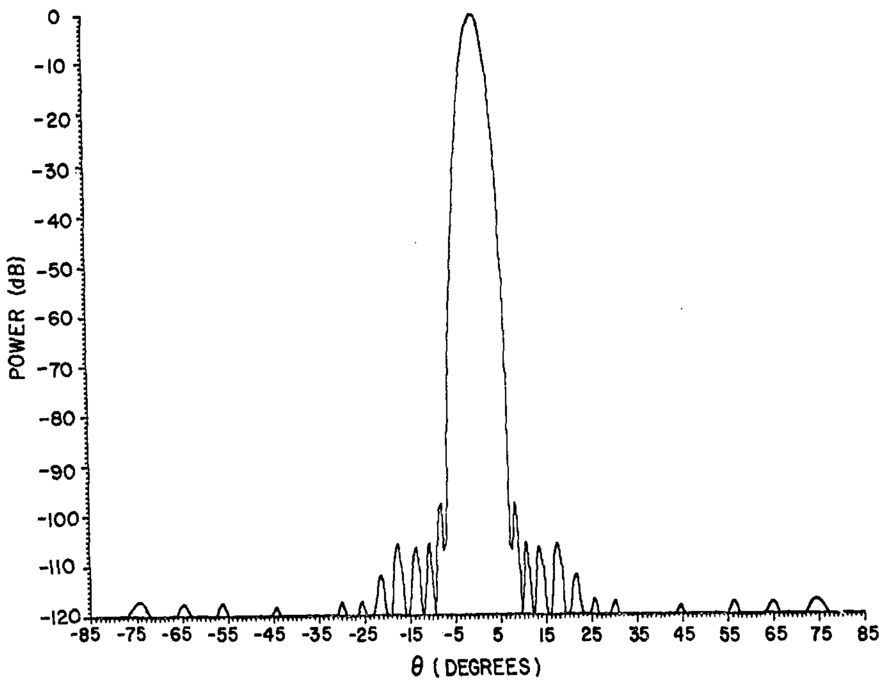

Fig. 10a — Two-way antenna pattern when 30 Hamming-weighted elements spaced $\lambda/2$ apart are moved through 15 elements on transmit and repeatedly on receive with the same aperture velocity

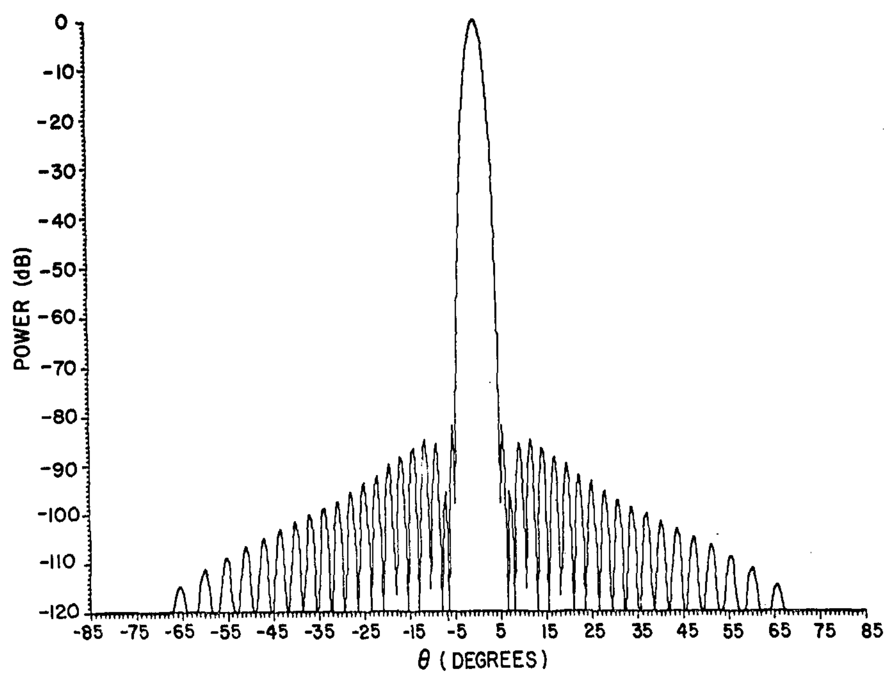

Fig. 10b — Two-way antenna pattern when 45 stationary Hamming-weighted elements spaced $\lambda/2$ apart are used both on transmit and on receive sidelobe reduction is obtained with the sweep. Also, the spectrum grating lobe moving in at large angles off boresight due to sweep on receive permits small sidelobes to occur at large angles, in contrast to the absence of sidelobes at large angles in Fig. 8a.

SECONDARY-APERTURE ANTENNAS

The possibility of using small phased-array primary feeds with focusing secondary apertures to obtain moving phase centers was considered. However, it was found that blockage effects by the feed in reflectors and unsymmetrical illumination on the edges of lenses produced undesirably large sidelobes in the filtered response of such antennas.

RELATED TECHNOLOGY

Bickmore discusses time-modulated apertures in antennas in Ref. 2. He used the modulation to obtain multiple frequency-resolvable simultaneous beams in space or to obtain variable aperture amplitude weighting via switches instead of variable power splitters.

CONCLUSIONS

On the basis of this evaluation, it appears that moving the phase centers of phased arrays on transmit and/or receive and properly filtering the receiver provides significant benefits in the form of unwanted sidelobe suppression. The available Doppler shift gives antenna designers a new dimension that may have many uses.

REFERENCES

1. U.S. Patent 3,412,405, Nov. 19, 1968, "Side Lobe Response Reducing System," Raymond E. Crotty and Clinton G. Goss, inventors. Assigned to Motorola Inc.

2. R.W. Bickmore, "Time versus Space in Antenna Theory," Chapter 4 in *Microwave Scanning Antennas, Volume III - Array Systems*, R. C. Hansen, editor, Academic Press, 1966.